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THESIS

SHIFT AND DUTY SCHEDULING OF SURGICAL TECHNICIANS IN NAVAL HOSPITALS

by

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September 2004

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Surgical technicians at Naval hospitals provide a host of services related to surgical procedures that include handing instruments to surgeons, assisting operating room nurses, prepping and cleaning operating rooms, and administrative duties. At the Naval Medical Center San Diego (NMCSD), there are 83 surgical technicians that must be scheduled for these duties. The three military and one civilian hospital interviewed for this thesis manually schedule these duties. Weaknesses of these manual schedules exposed during interviews at these hospitals include assignment inequities and the time needed to create them. This thesis reports on an optimization based and spreadsheet implemented tool developed to schedule surgical technicians for both daily and weekly duties at a Naval hospital. We demonstrate the tool for the surgical technician department at NMCSD. The schedulers at NMCSD verify the utility of the developed tool and cite a drastic reduction in the time required to generate timely, equitable, and accurate schedules. The study also investigates historical operating room usage data and makes suggestions for improving scheduling practices based on these data.

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SHIFT AND DUTY SCHEDULING OF SURGICAL TECHNICIANS IN NAVAL HOSPITALS

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ABSTRACT

Surgical technicians at Naval hospitals provide a host of services related to surgical procedures that include handing instruments to surgeons, assisting operating room nurses, prepping and cleaning operating rooms, and administrative duties. At the Naval Medical Center San Diego (NMCSD), there are 83 surgical technicians that must be scheduled for these duties. The three military and one civilian hospital interviewed for this thesis manually schedule these duties. Weaknesses of these manual schedules exposed during interviews at these hospitals include assignment inequities and the time needed to create them. This thesis reports on an optimization based and spreadsheet implemented tool developed to schedule surgical technicians for both daily and weekly duties at a Naval hospital. We demonstrate the tool for the surgical technician department at NMCSD. The schedulers at NMCSD verify the utility of the developed tool and cite a drastic reduction in the time required to generate timely, equitable, and accurate schedules. The study also investigates historical operating room usage data and makes suggestions for improving scheduling practices based on these data.

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I would also like to thank my wife, Lesley, for initially providing the impetus for this thesis subject from her observations in the Operating Rooms at the Naval Medical Center San Diego and also for putting up with my many educational endeavors in the last nine years. Finally, I would like to thank my two children Peyton and Lindsey for getting by without playing with Dad as I completed the writing of this thesis.

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I. INTRODUCTION

A. NAVY SURGICAL TECHNICIANS

Surgical technicians are enlisted sailors who assist surgeons and operating room nurses during surgical procedures. Their primary duties are to setup and hand required instruments and equipment to the operating surgeon. The U.S. Navy uses surgical technicians at all of its major hospitals and, like staff at any major hospital, these technicians must be scheduled both daily and multi-weekly for surgical cases and other duties. The U.S. Navy does not currently employ any scheduling software or service for scheduling medical personnel. This thesis develops optimization models to schedule Navy surgical technicians and implements them using Microsoft Excel [Microsoft, 2004] with the add-in Premium Solver [Frontline Systems, 2004]. The resulting models provide daily and six-week schedules superior to those that are currently being produced by hand.

B. HOSPITALS

We base our models on a series of interviews conducted at three Naval hospitals and one civilian hospital (Figure 1). Each of these hospitals has between 14 and 20 operating rooms staffed by three shifts (AM e.g., 0645-1515; PM e.g., 1445-2315; and night e.g., 2245-0715) of surgical technicians. Technicians have different skill sets that divide them into different groups. For every operating room surgery performed, all three Naval hospitals use two surgical technicians. Daily technician schedules follow a fixed operating room template that indicates the type of surgical case conducted in each operating room for a given day of the week. In each of the three Naval hospitals, cases are only planned for the AM shift Monday thru Friday. The PM shift supports cases that extend beyond the AM shift, and the night shift handles emergency cases and preparations for the following day.

In addition to the daily schedule, each hospital also has a duty section. A *duty section or duty* is an additional assignment such as hours added to a shift, working a weekend shift, or standing a pager call. The duty section also requires a schedule of technicians that accounts for their availability, skill set, and personal desires.

Scheduling

1. What tool, if any, is used to schedule technicians?
2. If no tool is used, how are the following considerations taken into account:
    a. Fairness between personnel?
    b. Day/night rotations?
3. How many shifts are scheduled and what are they?
4. How many operating rooms does the hospital have and are they all used daily?
5. What is the daily requirement for surgical technicians and how are personnel distributed between departments, operating rooms, etc.?
6. How are the night crew duties different from the two other shifts given there are no scheduled cases?
7. What are some of the issues that add to the turn-over time between cases?
8. What would you change about the schedules?
9. How long does it currently take to produce a schedule?
10. How far in advance is the schedule published?
11. How many days (shifts) are on a published schedule?
12. What is the biggest complaint about published schedules?

Personnel

13. What is the ideal number of personnel required? What is the actual number of personnel assigned with respect to this ideal?
14. What is the break policy for surgical technicians, both during cases and in-between?
15. How are breaks arranged? Does it vary by procedure length? Are the breaks scheduled?
16. Are there any incentives to working the late shift?

General

17. Does the hospital have an Operations Research Department?

Required Data

18. Obtain copy of Main Operating Room (MOR) scheduling matrix

A questionnaire used at four hospitals to collect information about scheduling and requirements.

Figure 1. Interview Questionnaire

1. Naval Medical Center San Diego

The surgical technician department at the Naval Medical Center San Diego (NMCSD) consists of 83 technicians working a three-shift schedule five days per week and a two-shift schedule during a weekend. Schedules are currently created by hand for a seven-day duty section and also for the daily operating room schedule. Operating room use is guided by a template (Table 1) for its 18 operating rooms. This guide reserves specific rooms for specific types of cases. The surgical technician scheduler receives a

finalized daily plan for operating room cases by 1100 the previous day and uses this information to schedule technicians to specific operating rooms for the following day's cases. A minimum of two technicians are assigned to each operating room. Each operating room has a minimum of eight hours worth of cases. Additionally there are two technicians per clinic assigned to two separate clinics during the AM shift.

The NMCSD duty section schedule requires five individuals during weekdays and six technicians on weekends. This duty provides coverage during the weekdays for cases that go past the AM shift and provides all staff for the weekend shifts. The surgical technician scheduler attempts to post a six-week schedule that assigns technicians to these duties two weeks before the first scheduled event. One of the biggest complaints by current staff with respect to this schedule is that it is not generated and posted far enough in advance.

2. Naval Medical Center Bethesda

The surgical technician department at the Naval Medical Center Bethesda consists of 54 technicians working a three-shift schedule five days per week and two twenty-four hour shifts (12 hours on followed by 12 hours of call) that cover the weekend. In addition to this two-person weekend duty, there are two additional individuals on pager call. Like all hospitals in this study, surgical technicians normally do not rotate between shifts; that is, a day shift member does not switch to a PM or night shift. Naval Medical Center Bethesda has a total of 14 operating rooms for surgical cases.

Currently, the Bethesda surgical technician Leading Petty Officer (LPO) releases a 72-hour schedule based on planned surgical cases that she updates every 24 hours as cases become more certain. She assigns two or three surgical technicians to each case by 1400 the prior day. One of the biggest complaints among Bethesda's surgical technicians is that hospital departments regularly schedule more than the eight hours of surgical time for a given operating room during the AM shift.

Table 1. NMCSD Main Operating Room Schedule

Template used by NMCSD to schedule surgical technicians. Operating rooms reserved for eye, ear nose and throat (ENT), urology, podiatry, and oral surgery require no surgical technicians. All others require a minimum of two technicians.

Rm	Monday	Tuesday	Wednesday	Thursday	Friday
1	Ortho Hand	Ortho A / Ortho Knee	Derm (2nd, 4th) / GYN (1st, 3rd, 5th) General Surgery	Ortho Hand	Ortho Hand (1st, 3rd, 5th) Oral Surgery (2nd & 4th)
2	Ortho Hand	Oral Surgery	ENT	Ortho Peds	Oral Surgery
3	Urgent / Emergent / Add-0ns	Eye	Eye	Eye	Eye
4	ENT	ENT	ENT	Urgent / Emergent / Add-0ns	ENT
5	Plastics	Urology	Plastics	Plastics	ENT
6	General Surgery	General Surgery	Ortho A / Ortho Knee	General Surgery	General Surgery
7	General Surgery	General Surgery	Podiatry General Surgery	General Surgery	General Surgery
8	Plastics	Urology	Urology	Urology	Urology
9	Urgent / Emergent / Add-0ns	Urgent / Emergent / Add-0ns	Urgent / Emergent / Add-0ns	Urgent / Emergent / Add-0ns	Urology
10	General Surgery (Peds) General Surgery	ENT	Ortho A	General Surgery (Peds)	Ortho A
11	ENT	Ortho (Peds)	Urology	Urology Peds & Ortho B (Alternate Weeks)	Urgent / Emergent / Add-0ns
12	Ortho B	Ortho A	Oral Surgery	Ortho B	Ortho A
13	Ortho A	Urgent / Emergent / Add-0ns	GYN	Ortho Spine	Podiatry
14	GYN	GYN	GYN	GYN	GYN (1st, 3rd, 5th) Ortho Hand (2nd & 4th)
15	General Surgery (Vasc)	Ortho Spine	Ortho B	General Surgery (Vasc)	Ortho Knee
16	CT	CT	Urgent / Emergent / Add-Ons	CT	CT
17	Neuro	Neuro	Neuro	Neuro	Neuro
18	Ortho Major Joint	Ortho Knee	Ortho Major Joint	Ortho Knee	Ortho Major Joint

3. Naval Medical Center Portsmouth

The surgical technician department at the Naval Medical Center Portsmouth consists of 62 active duty technicians and 14.8 civilians (includes part-time technicians). The technicians work one of three shifts Monday thru Friday or one of two weekend shifts from Friday thru Sunday. Civilian technicians only work from 0645 to 1500 each day. Like Bethesda, a 72-hour schedule is normally provided by the hospital but the final daily assignments are done by hand for the following day's surgical cases.

There are four divisions of surgical technicians. Technicians spend a year rotating through these divisions in either 24 or 42-month standard length tours. The difference in tour length depends on whether the technician is fully qualified when he or she arrives or is coming directly from the Navy "C" school. The biggest complaint among technicians is a routine of scheduling more than the 8.5 hours limit in each operating room resulting in surgical technicians working beyond their normal shift times.

4. Scripps Mercy Hospital, San Diego California

The surgical technician department at the civilian Scripps Mercy hospital in San Diego, CA consists of 22 personnel working three shifts. Two of these shifts have variable lengths between eight and 12 hours. There are a total of 11 operating rooms and four outpatient operating rooms that use surgical technicians. Each surgical procedure uses only a single surgical technician.

Scripps Mercy schedules surgical technicians over a four-week period. The schedule is manually created and displayed using Microsoft Excel. The schedule takes approximately two weeks to generate and is normally a continuous "work in progress." The four-week schedule merely outlines which employees are working which shift, on what day, and for what length of time. The daily schedule is consistent with this, but assigns technicians to cases. The biggest complaint with surgical technicians at Scripps Mercy is dissatisfaction with posted schedules when they do not receive their desired work hours.

C. HOSPITAL SIMILARITIES

The four hospitals share many similarities. Each of them uses three shifts and assigns surgical technicians to a specific operating room. Table 2 presents some details.

Table 2. Hospital Comparisons

The table shows the number of operating rooms at four hospitals interviewed for this thesis and the number of surgical technicians typically assigned during a weekday. All scheduled procedures are scheduled to start during the AM shift. The PM shift supports cases that extend beyond the AM shift, and the night shift handles emergency cases and preparations for the following day.

	NMCSD	Bethesda	Portsmouth	Scripps Mercy
Operating Rooms	20	14	17	15
Operating Rooms not scheduled	2	-	-	-
Technicians for AM (Shift 1)	69	46	24	14
Technicians for PM (Shift 2)	9	6	10	7
Technicians for Night (Shift 3)	5	3	5	1

Another important similarity is that personnel are not rotated though shifts as they are in other industries. This policy results in not having to worry about issues such as internal time clock changes when employees are moved from late shifts to early shifts. The non-rotation of personnel also simplifies the creation of tools that automatically generate work schedules.

The other similarity that three of the four hospitals share is that a schedule is generated daily based on planned surgical cases. All three military hospitals create daily schedules using a template that pits specific case types against operating rooms. The creation of a scheduling tool can address this requirement by taking into account considerations such as equity, planned vacation or absences, and personnel qualifications.

D. HOSPITAL DIFFERENCES

Differences between hospitals are primarily the differences between civilian (Scripps Mercy) and military hospitals. Whereas the military hospitals all have three fixed length shifts, Scripps Mercy hospital uses varying shift lengths during two of the three shifts. The purpose of this varying shift length is to ensure that there is enough coverage for the busiest parts of the day.

The next major difference between the hospitals is that Scripps Mercy uses a single surgical technician for most cases. The use of single surgical technician appears to be a civilian standard. The military hospitals use two to three technicians for each case. This two or three person technician team includes one or two students who are under

instruction of an experienced technician. As the same surgical technicians are used in each of the main departments in a hospital, they are normally rotated through respective departments after one year. This procedure is primarily to familiarize the technicians with all departments and to support their possible assignment to any department at Naval hospitals worldwide. Departments that use surgical technicians at Navy hospitals are Labor and Delivery and Gynecology, Orthopedics, Cardio Thoracic (CT), Neurosurgery, Vascular, General surgery, and Plastic surgery.

Another difference is that all operating room staff at Scripps Mercy pitch in to clean and prep the operating room for follow on cases. The result of this team effort is that Scripps Mercy has the shortest turn-around time between cases at all hospitals in San Diego.

E. THESIS CONTRIBUTION AND ORGANIZATION

This thesis and the resulting models provide a tool to schedule surgical technicians at Naval hospitals. The study also investigates historical operating room usage data and makes suggestions for improving scheduling practices based on these data and from practices of the single civilian hospital interview for this study. These suggestions include the use of a single surgical technician during operating room cases, and a staggered shift to address the long cases between the AM and PM shifts. The models developed have been validated by a limited deployment at NMCSD. In the future, the surgical technician department at NMCSD plans to fully implement both models.

This thesis is organized into five chapters. Chapter I provides a brief overview and outlines the thesis. Chapter II presents a review of some related literature and an overview of scheduling software and scheduling services. Chapter III summarizes operating room data from NMCSD for 2003. Chapter IV presents details about the developed optimization models and provides information obtained from implementing these models at NMCSD. Chapter V presents conclusions and recommendations for further research.

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II. SCHEDULING LITERATURE AND SOFTWARE

A. INTRODUCTION

There are a wide variety of solutions available for personnel scheduling that include pre-packaged software, web-based services, and custom solutions derived either from the open literature or through the use of hired consultants. From a review of the available literature, it is clear that the use of the classical assignment and transportation models [Nahmias, 2001] are the preferred solutions when scheduling groups of personnel over multiple time periods. When scheduling personnel, the scheduler must be mindful of state and federal laws that apply and guidance outlined in the Fair Labor Standards Act.

B. SOFTWARE PACKAGES

A representative package for the first type of software, essentially a display and printing package, is Engineered Software Solutions (ESS) Scheduler [ESS, 2004]. This program provides a set of tools to allow the creation of specific facilities and/or departments and its associated employees. The user then manually assigns employees to the required defined work durations. The program allows the user to enter vacation days, sick time, and also holiday schedules. Summary data for each employee and each facility can be displayed and printed. The benefit of this type of program is that it provides a repository for schedules and displays conflicts in manually generated schedules. The program costs $199 [ESS, 2004].

A software package that generates schedules for employees based on shifts and costs only $68 is Shift Scheduler Continuous [BizPeP Business Support Software, 2004]. The software is an Excel Add-In and can schedule up to 150 shifts. Though constraints on employees are very limited, time and maximum continuous hours worked, the program does automatically schedule a large number of employees. This program would not suffice for an organization with employees of many different levels of skill, such as we find at the hospitals in this study.

The last type of commercial product is a service that requires users to login to a secure website to use the software. This allows not only administrators but also regular

employees to login from any computer with Internet access to either view schedules or enter information such as planned vacations, medical appointments, or emergency absences. An example of this type of service is Just in Time [Lightening Bolt Solutions, 2004]. The service allows a user to login and enter information and generate schedules. Just in Time relies on heuristics to solve what they call the classical “NP-hard” problem [Lightening Bolt Solutions, 2004]. Though not guaranteed to be optimal, the service provider claims the results will meet most user generated schedule requirements. The pricing structure for this service is based on the number of individuals being scheduled. For a department with 75 personnel, the annual cost of this service is approximately $753 with an $18,750 initial start-up fee.

In an article about Recreational Equipment, Incorporated (REI), Haeberle [2003] discusses the implementation of a web-based scheduling service similar to Just in Time called Workbrain for Retail. In addition to cutting over five hours from store managers’ weekly duties by automating employee scheduling, the system also improved employee morale as they could request specific shifts, change shifts with other employees, and have access to the schedule at all times via the Internet.

C. SCHEDULING MEDICAL PERSONNEL

Literature on scheduling medical personnel is diverse. Areas include staffing requirements of operating rooms as discussed by Dexter and O’Neill [2001] and scheduling of physician rotation to different departments in a 12-month period or shift assignments as discussed by Franz and Miller [1993]. There are also a host of articles that discuss scheduling from a more mathematical perspective, these include Ross and Zoltners [1979]; Beaulieu, Ferland, Gendron, and Michelon [2000] who develop a model to schedule physicians in an emergency room; and Klein, Dame, Dittus and Debrota [1990] who also develop and implement a model for physician call schedules at a hospital.

Franz and Miller [1993] discuss complications with matching personnel abilities with tasks and operational requirements on the timing and staffing of certain tasks. They state that multi-period staff assignments include a myriad of constraints, which may or may not be possible to satisfy simultaneously. Finally, the authors note that these types

of problems have wide applicability in organizational settings such as the military, organizational training programs, and public sector service delivery systems.

Ross and Zoltner [1979] provide a comprehensive discussion on weighted assignment models. They describe the weighted assignment model as a set of tasks that must be divided among a set of agents, and each task must be completed by only one agent. The authors go on to state that the general formulation of these types of problems closely parallel the classical assignment models, the transportation models, knapsack models, and various fixed charge models. They point out that a class of weighted transportation models with integer restrictions on the decision variables has emerged as an important model type. Though they do not solve a particular scheduling problem, they do present a series of problems that can be solved by the weighted assignment problems. In this thesis the weighted transportation model is the underlying model that provides the scheduling solution for the surgical technician schedules.

D. STATE AND FEDERAL LABOR LAWS

This thesis applies to the U.S. military and there are currently no state or federal laws that directly apply to military members that influence the scheduling of surgical technicians. In general, employees in the health care profession are under guidance from "Fact Sheet #53 – The Health Care Industry and Hours Worked" of the Fair Labor Standards Act [U.S. Department of Labor, 2004]. In simple terms this fact sheet outlines that a hospital worker can work for 40 hours per week before he must be paid overtime. There are no federal rules that apply to employee breaks and a lunch period is not mandated by federal law. All military hospitals queried in this thesis offer both breaks and lunch periods to surgical technicians. Due to the variable nature of medical cases, both breaks and lunch periods are dependent on a specific technician's daily schedule and arrangements made with other technicians to provide coverage during long surgical cases.

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III. NAVAL MEDICAL CENTER SAN DIEGO

A. INTRODUCTION

A significant amount of data was collected from one-on-one interviews at three Naval and one civilian hospital. The one-on-one interviews were with either the leading petty officer (LPO) of the surgical technicians or the surgical technician scheduler.

In addition to these interviews, we reviewed an entire year's (2003) operating room data from the Naval Medical Center San Diego. The operating room data provide a historical perspective on the number of cases, type of case, length of case, day of week, and operating room usage. While not used directly for scheduling technicians, these data provide valuable insight into the use of surgical technicians and also whether changes to scheduling procedures can be implemented to better use personnel and meet surgical case loads.

B. NMCSD 2003 OPERATING ROOM DATA

We obtain from NMCSD daily operating room data from all of 2003. All data are in spreadsheet form in Microsoft Excel. Table 3 displays a sample of the data that includes Procedure Date, Case Type, Room Number, Case Number, In Room Time, Leave Room Time, In Room/Leave Room Minutes, Operation Start Time, Operation End Time, and Operation Start/End total minutes.

Table 3. Sample of NMCSD Operating Room Data

Sample of data obtained from NMCSD showing various statistics from cases for a given date.

ProcedureDate	Case Type	Room #	Case #	In Room Time	Leave Room Time	om / Leave	Operation Start Time	Operation End Time	Operation Start / End
02-Jan-03	SE	03	1	7:45	10:40	175	8:19	10:25	126
02-Jan-03	AO	05	1	8:21	12:15	234	9:20	12:10	170
02-Jan-03	AO	05	2	12:35	15:35	180	13:01	15:20	139
02-Jan-03	SE	06	1	7:53	9:35	102	8:12	9:33	81
02-Jan-03	SE	06	3	11:01	13:05	124	11:25	12:57	92
02-Jan-03	SE	07	1	7:35	11:00	205	8:05	10:53	168
02-Jan-03	AO	07	2	12:05	13:50	105	12:28	13:45	77
02-Jan-03	AO	07	3	14:55	18:35	220	15:28	18:30	182
02-Jan-03	SE	10	1	7:55	9:35	100	8:22	9:28	66
02-Jan-03	SE	10	2	10:00	10:55	55	10:12	10:50	38
02-Jan-03	SE	10	3	11:25	13:07	102	11:55	13:00	65
02-Jan-03	SE	10	4	13:55	15:18	83	14:22	15:08	46
02-Jan-03	SE	11	1	7:30	11:33	243	8:38	11:28	170
02-Jan-03	SE	11	2	12:12	15:11	179	13:03	15:05	122
02-Jan-03	SE	12	2	11:30	15:20	230	12:13	15:10	177
02-Jan-03	SE	13	1	7:35	10:05	150	8:12	10:00	108
02-Jan-03	SE	13	2	10:30	11:41	71	10:56	11:31	35
02-Jan-03	SE	13	3	12:43	16:35	232	13:14	16:30	196
02-Jan-03	SE	14	1	7:40	8:46	66	8:25	8:37	12
02-Jan-03	SE	14	2	9:16	11:23	127	9:45	11:09	84
02-Jan-03	SE	14	3	11:49	15:19	210	12:26	14:53	147
02-Jan-03	AO	14	4	17:37	18:14	37	17:50	18:05	15
02-Jan-03	AO	15	1	8:02	12:15	253	8:35	12:08	213
02-Jan-03	AO	15	2	12:50	16:18	208	13:27	16:08	161
02-Jan-03	AO	15	3	14:15	15:45	90	14:45	15:00	15
03-Jan-03	SE	02	1	7:43	11:30	227	8:24	11:25	181
03-Jan-03	SE	02	2	12:25	17:39	314	12:30	17:18	288

From this information, we construct a monthly picture that includes a count of cases by operating room and in which shift the cases take place. We collect and summarize data for each day of the month. Additionally, we calculate averages, standard deviation (characterization of the data scatter), variance (square of the standard deviations), median (point where half of total distribution is above and below), mode (value which occurs with the greatest frequency), minimum, and maximum number of cases per shift, number of operating rooms per day, and number of cases per day. Table 4 presents a sample of this data. We generate a similar table for each month.

Table 4. NMCSD Number of cases for Surgical Technicians by Operating Room

Reduced data by operating room, shift, and month. The numbers indicate the cases performed in a specific operating room. Summary data is calculated for each of the days of the month.

JAN	OR1			OR2			OR3			OR4			OR5			OR6		
DAY	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
1																		
2													2			2		
3																2		
4																		
5																		
6													2	1		4		
7																1		
8																		
9																3		
10																3		
11																		
12																		
13	2			1									2	1		2		
14	2	1		2									2			1		
15	1															3		
16	2			2	1								1			2		
17	2															3		
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21	1															2	2	
22	2												2			2		
23	2			2	1					1			1			1	1	
24	1															3		
25																		
26																		
27													1	1		2		
28	2															1		
29	2	1											3			2		
30	2			2									2			2		
31	1															3		
	22	2	0	9	2	0	0	0	0	1	0	0	18	3	0	44	3	0
	24			11			0			1			21			47		

JAN	OR7			OR8			OR9			OR10			OR11			OR12		
DAY	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
1																		
2	2	1								4			2			1		
3										1						2		
4																		
5																		
6	1	1		1												2	1	
7	1												3			2		
8										2	2							
9	2	1					3						1			2		
10													1			3		
11																		
12																		
13	1			3						3						3		
14	2	1					1						2			2		
15	2						1									1		
16										3			5	1		1	1	
17	3									3						1		
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21	1	1					2						2			2		
22	3									1								
23	3						2			3			2	1		3		
24	1									3	1		1			2	1	
25																		
26																		
27	1			2						5						1		
28	2												2	1		3		
29	3						1			1								
30	2									2			2	1		2	1	
31																		
	30	5	0	6	0	0	10	0	0	31	3	0	23	4	0	33	4	0
	35			6			10			34			27			37		

JAN	OR13			OR14			OR15			OR16			OR17			OR18		
DAY	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
1																		
2	3			3	1		2											
3				1	1								1					
4																		
5																		
6				2			2		1				2	1				
7	2									2			2					
8	1			3				1					1			2		
9	2			2			1	1	1	2			1					
10				3			3			1	1					1		
11																		
12																		
13	3			2	2		3	1		2			2			2		
14	2			3			1	1		1			1					
15	2			2	1					1						2	1	
16	2			4	2		2			2						2		
17				3			3			1	1		2			2		
18																		
19																		
20																		
21				3			2	2		1			1			1		
22	2			3			2	1		1	2		1				1	
23	2			3	1		3			1			3			2		
24				1			2						2			2		
25																		
26																		
27				3	1		2	1					1			2		
28	2		1	1			2	1					1			1	1	
29	1			2			1	2					2			1		
30	2	1		3	1		1	1					2			2		
31				2	2		3	1	1				2			2		
	26	1	1	49	12	0	35	13	3	15	4	0	27	1	0	24	3	0
	28			61			51			19			28			27		

DAY	Total Cases Per Day	OR s Used	Cases by shift S1	S2	S3
1					
2	23	9	21	2	0
3	8	5	7	1	0
4					
5					
6	21	8	16	4	1
7	13	7	13	0	0
8	12	6	9	3	0
9	22	10	19	2	1
10	16	7	15	1	0
11					
12					
13	35	14	31	4	0
14	25	13	22	3	0
15	17	9	15	2	0
16	33	12	28	5	0
17	24	10	23	1	0
18					
19					
20					
21	23	11	18	5	0
22	23	11	19	4	0
23	38	16	34	4	0
24	20	10	18	2	0
25					
26					
27	23	10	20	3	0
28	21	10	17	3	1
29	22	11	19	3	0
30	31	13	26	5	0
31	17	6	13	3	1

	S1	S2	S3					
Average number of cases per shift	19	3	0	(Arithmetic Mean)	Average number of Ors used per day	10	Average number of Cases per day	22
Standard Deviation	7	1	0	Characterizes the degree of scatter	Standard Deviation	3	Standard Deviation	7
Variance	45	2	0	standard deviation squared	Variance	8	Variance	56
Median	19	3	0	Point where half of total distribution is above and below	Median	10	Median	22
Mode	19	3	0	Value which occurs with the greatest frequency	Mode	10	Mode	23
Minimum Number of Cases	7	0	0		Minimum Number of Ors used per Day	5	Minimum Number of Cases per Day	8
Maximum Number of Cases	34	5	1		Maximum Number of Ors used per day	16	Maximum Number of Cases per day	38

1. Operating Room Usage

NMCSD uses a template to reserve types of cases for specific operating rooms (see Table 1), Table 5 shows not all reserved rooms typically have cases. Table 5 shows that the planned number of rooms per day varies between 11 and 16 but the average number of rooms with cases over each day of the week varies between 10 and 13. These data show that the template is only a guide and that the actual values for operating rooms scheduled differ.

There are currently 46 technicians at NMCSD that scrub for cases during the AM shift. Assuming two technicians per operating room, Table 5 indicates that this number could be as low as 32 (plus four for the two clinics).

Table 5. Number of ORs Scheduled per Day

Shows number of operating rooms (ORs) planned and their corresponding average scheduled values for the entire year by day of the week.

Day	Mon	Tues	Wed	Thur	Fri
ORs Planned	16	12	12	16	11
Average ORs Used	12.4	9.9	10.2	13.1	9.7

2. NMCSD 2003 Data Summaries

We plot in Figures 2 through 5 the reduced data for all 12 months of 2003 that includes cases per shift and number of cases per day. These plots reflect several assumptions. First, we remove cases (Ear, Nose and Throat (ENT), Eye, Oral Surgery, Urology, and Podiatry)where surgical technicians are not required and are not used. We count a case that continues for more than one hour into the next shift as two cases. We do not show any weekend data; only one to four cases per month occur on the weekend. Based on the current staffing a twofold increase in weekend cases would not require additional personnel.

Figure 2 shows that the average number of cases per shift for the AM shift at NMCSD is approximately 23 with a minimum value of approximately five and a maximum value of 35. The large variances in January and December are due to the Christmas and New Year holidays when the hospital runs a reduced number of operating rooms.

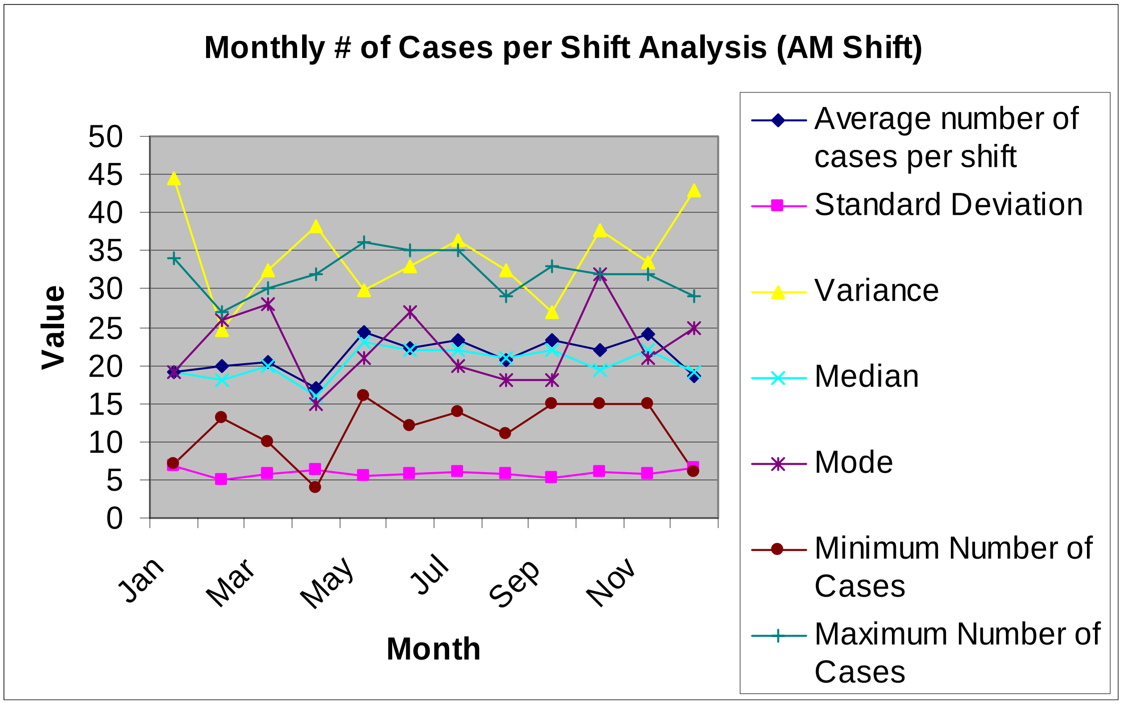

Figure 2. Number of Cases per Shift (AM Shift)

The average yearly value for number of cases during the PM shift is approximately five as depicted in Figure 3. Again, the large variance in December can be attributed to the modified schedules that result from the Christmas holiday.

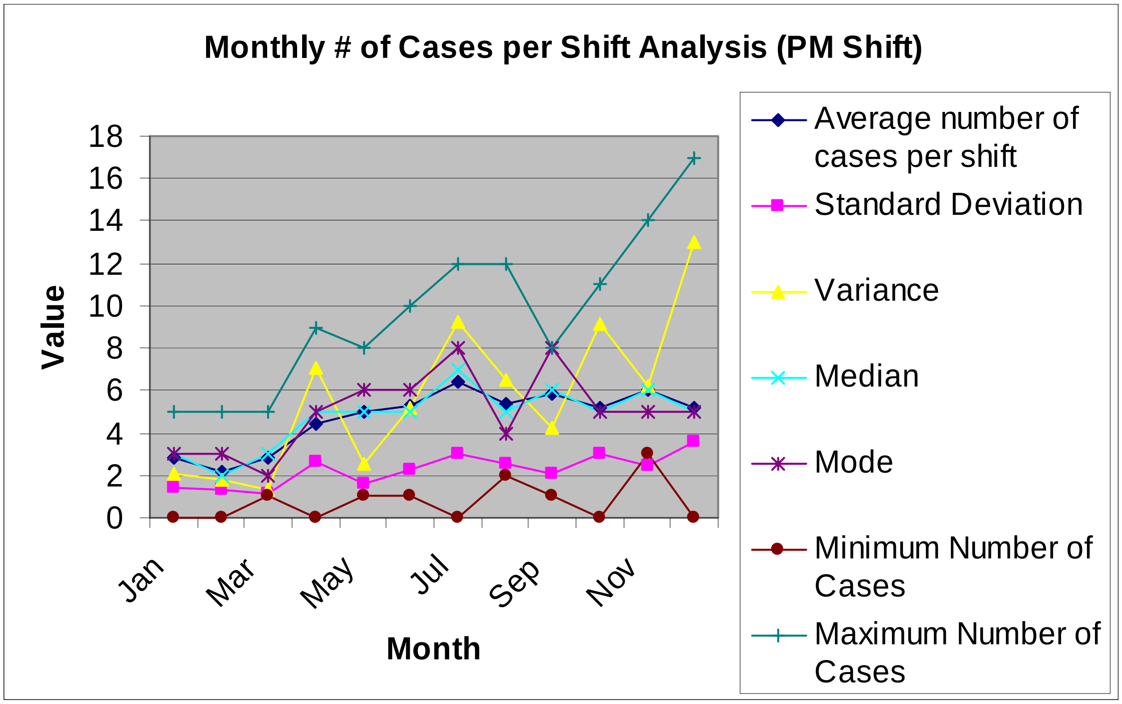

Figure 3. Number of Cases per Shift (PM Shift)

Figure 4 presents the data for the night shift. Throughout the year, the maximum number of cases during the night shift is only three cases so this is not a deciding factor when considering the amount of personnel required for staffing. NMCSD, as well as all other hospitals interviewed used night shift personnel to prepare operating rooms for the following day's cases.

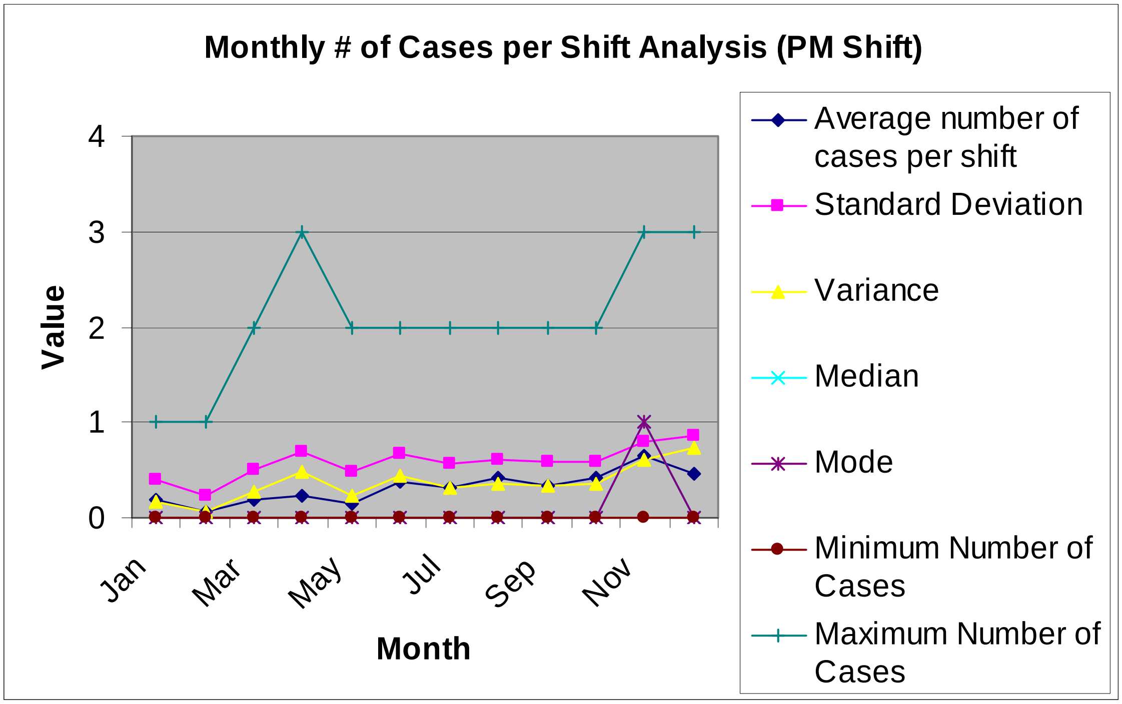

Figure 4. Number of Cases per Shift (Night Shift)

Figure 5 presents a summary of cases per day for each month. This chart shows that the maximum number of cases per day is fairly consistent at 40, the minimum number of cases on any given day is around 15, and that the number of cases per day varies considerably from month to month. The average number of cases for each month is around 30.

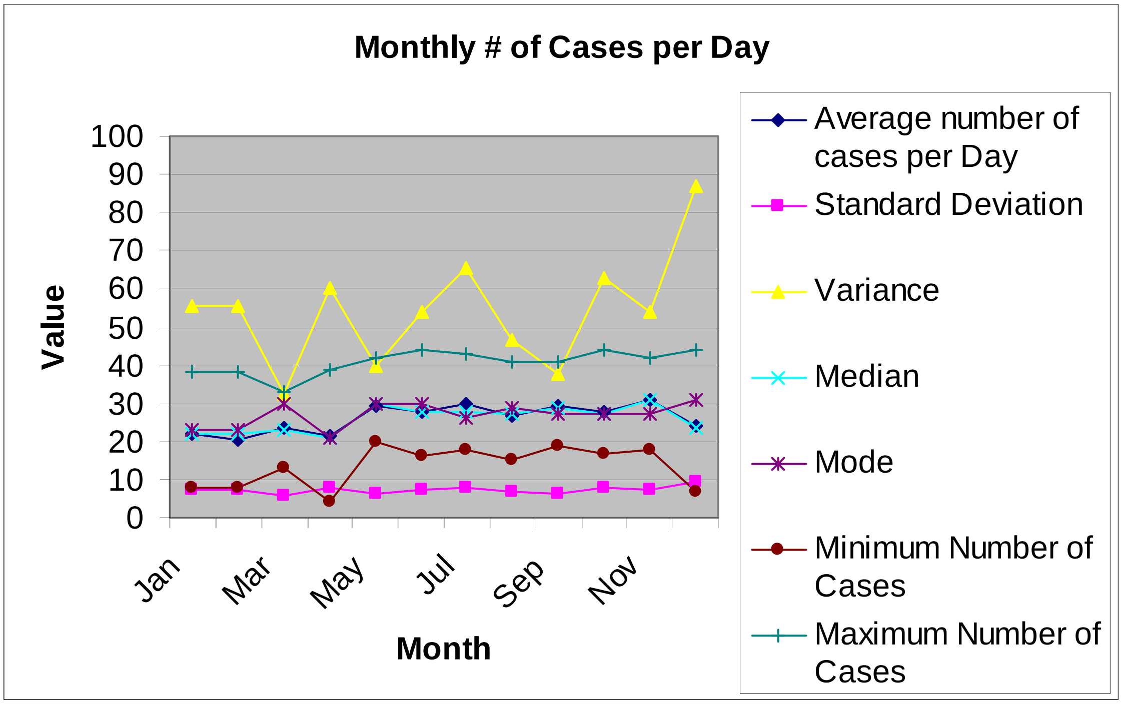

Figure 5. Number of Cases per Day

The data suggest opportunities to improve how NMCSD schedules the PM shift. There are many cases that start in the AM shift but end in the PM shift. NMCSD currently addresses this issue by having nine technicians that are assigned to the PM shift and a duty section of five to six technicians per day that work beyond the AM shift to cover these types of cases. The variance of cases in this shift is high enough that the daily duty section of additional personnel is one way of addressing this variance. Another possibility is to have staggered starting times for some technicians in the AM shift that will have the same net effect of the duty section each day in order to cover the spill over cases from the AM shift. This approach would be similar to the practice in place at Scripps Mercy hospital.

IV. MODEL DEVELOPMENT

A. INTRODUCTION

This chapter describes the two models created to address the surgical technician-scheduling problem at NMCSD. Both models use Excel [Microsoft, 2004] and Premium Solver Excel add-in [Frontline Systems, 2004]. Though these models are developed specifically for NMCSD, it seems a straightforward modification could address the scheduling requirements at the other three hospitals discussed in this thesis.

B. TEST CASE: DAILY SCHEDULE

Due primarily to its location and the ability to obtain and analyze an entire year's operating room data, NMCSD is our test case. A summary of the daily scheduling requirements for NMCSD is below:

- Daily scheduling requirement follows a fixed weekly operating room schedule. (Table 1 shows a sample schedule).
- Cases are only scheduled for the AM shift.
- A total of two technicians must be scheduled for each operating room that has at least one case.
- There are a total of four teams that have priority for specific types of cases; these teams include Team A: Cardio Thoracic, Neurological, and Vascular; Team B: Orthopedics; Team C: Obstetrics and Gynecology, and Plastics; and Team D: General Surgery.

C. SOFTWARE

Development of the daily and six-week scheduling models is done using Excel. Excel is widely available on government computers and is generally the standard for spreadsheet applications. Microsoft Excel's functionality is in its ability to enter data, analyze this data, and display the results in either tabular or graphical format [Simon, 2003]. Microsoft Excel contains an add-in software tool called Solver that provides a capability to solve linear, nonlinear, and integer problems. The scheduling of surgical technicians is a prime example of one of these problems.

The Solver add-in included with standard Excel is a product created by Frontline Systems. Unfortunately, the product is limited to 200 decision variables and 100 constraints [Frontline Systems, 2003]. For the daily problem described at NMCSD, there are approximately 800 variables for any given day. For the six-week schedule at NMCSD, there are approximately 504 variables for each week. The Premium Solver add-in provides the capability to solve linear and integer programming problems with up to 1,000 variables and with no limit on the number of constraints [Frontline Systems, 2003]. This limit is sufficient to solve the scheduling problems described above. The other benefit of this add-in is that it does not require the installation of a stand-alone program. Installations of stand-alone programs for unique tasks on government computers provide challenging information technology hurdles that are many times unable to be bypassed. For example, installation of software requiring Windows Registry entries on the Navy and Marine Corps Intranet (NMCI) [Electronic Data Systems Corporation, 2004] is prohibited.

D. DAILY SCHEDULE MODEL

The model used to solve the daily schedule is based on the classic transportation problem [Nahmias, 2001]. Below we show the formulation of the transportation problem as used in this thesis.

Indices:
s = surgical technicians (e.g., staff 1, staff 2 …)

r = room (e.g., room 1, room 2 …)

Data:
$\text{Score}_{sr} \equiv$ value of assigning technician s to room r
$\text{Demand}_{r} \equiv$ number of techs required in room r

Value:
Let $X_{sr} \equiv 1$ if staff s is assigned to room r and zero otherwise

Formulation:

$$\max \sum_{s,r} \text{Score}_{sr} X_{sr}$$

$$\sum_r X_{sr} \leq 1 \, \forall s$$

Such that: $$\sum_s X_{sr} = Demand_r \ \forall \text{r}$$

$$X_{sr} \text{ binary } \forall \text{sr}$$

The objective function provides an assessment of the total score for assigning staff to specific rooms. The score for any technician assigned to a specific room takes into consideration qualifications (priority for specific types of cases) and availability. The staff assignment is simply a one or zero depending on whether a technician is assigned to a particular room or not.

We use the following scoring formula to model the desire to have priority for specific types of cases and to encourage or discourage diversity:

$Score_{sr} = W_{sr} + \left(\frac{H_{sr}}{\sum_r H_{sr}} \right) I_{sr}$. W_{sr} is the weight for assigning surgical technician *s* to room *r* based on priority for specific types of cases. H_{sr} is how many times technician *s* has been assigned to cases of the type occurring in room *r* over a user defined period of time and I_{sr} is +1.0, -1.0, or 0.

As an example, we present a problem that requires the assignment of four surgical technicians to two operating rooms requiring two technicians per room. The weighting (or cost) shown in each row is used to provide two distinct scheduling characteristics. The first is the weighting assigned to each room (W_{sr}). These values are 10, 1, or 0. The value of 10 would be assigned if it is preferred to assign the staff member to this type of case. A value of one would allow assignment of the staff with no preference between types of cases. A value of zero discourages the staff from being assigned to that room (we did not take the additional step of eliminating variables with zero objective function coefficients). The values in the last two columns are a count of the number of times the staff member has been assigned to that type of case over the last 30 days. These last two columns allow the consideration of equity in scheduling between staff members creating a weighting ratio of the count of a particular room assignment over the sum of all room assignments. Using I_{sr} = -1.0 when W_{sr} = 10 (primary assignment) encourages diversity

between priority assignments while I_{sr} =1.0 when W_{sr} = 1 discourages diversity in non priority assignments. I_{sr} = 0 when W_{sr} = 0.

From	**To**			
Staff	**Room 1 Oral**	**Room 2 Neuro**	**Out of 30 days Oral**	**Out of 30 days Neuro**
1	P = 10	NP = 1	30	0
2	N = 0	P = 10	0	20
3	NP = 1	NP = 1	5	25
4	P = 10	P = 10	6	21

Primary duty (P), no preference (NP), and do not schedule (N)

For this example, we have:

$Score_{11} = 10 - 30/(30 + 0) = 9$
$Score_{12} = 1 + 0/(30 + 0) = 1$
$Score_{21} = 0 + 0/(20 + 0) = 0$
$Score_{22} = 10 - 20/(20 + 0) = 9$
$Score_{31} = 1 + 5/(5 + 25) = 1.17$
$Score_{32} = 1 + 25/(5 + 25) = 1.83$
$Score_{41} = 10 - 6/(6 + 21) = 9.78$
$Score_{42} = 10 - 21/(6 + 21) = 9.22$

So we seek to maximize

$9X_{11} + 1\,X_{12} + 9\,X_{22} + 1.17\,X_{31} + 1.83\,X_{32} + 9.78\,X_{41} + 9.22\,X_{42}$

subject to the following constraints (ensures that a staff can only be assigned to one room):

$X_{11} + X_{12} \leq 1$
$X_{21} + X_{22} \leq 1$
$X_{31} + X_{32} \leq 1$
$X_{41} + X_{42} \leq 1$

and (ensures that there are two technicians assigned to each room):

$X_{11} + X_{21} + X_{31} + X_{41} = 2$
$X_{12} + X_{22} + X_{32} + X_{42} = 2$

1. Daily Model Excel Implementation

The daily Excel model consists of six distinct parts for each of the five days for which it is used. The user is first required to enter whether or not a technician is available on that day by entering a one or zero in the availability column. This selection also takes into consideration whether or not they should be preferentially scheduled, scheduled equally with everyone else, or not scheduled for a specific surgical service. Table 6 presents an excerpt from the availability and specialization matrix. The values of 0, 1, or 10 in the specialization matrix are as described above in the example.

Table 6. Availability and Specialization Matrix

OR Staff	Avail.	1 Ortho	2 Ortho	3 Add On	5 Plastics	6 Gen Surg	7 Gen Surg	8 Plastics	9 Add On	10 Gen Surg	12 Ortho	13 Ortho	14 Gyn	15 Vasc	16 CT	17 Neuro	18 Ortho
McKew	1	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	1
Mitchell	0	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	1
Beben	1	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	1
Wright	1	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	1
Fellman	1	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	1
Capuli	1	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	1
Allsup	0	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	1
Chavez	1	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	1
Lumby	1	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	1
J Sanchez	1	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	1
Seal	1	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	1
Cummings	1	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	1
	0	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	1
E Sanchez	1	10	10	1	1	1	1	1	1	1	10	10	1	1	1	1	10
Kennedy	0	10	10	1	1	1	1	1	1	1	10	10	1	1	1	1	10
Martin	1	10	10	1	1	1	1	1	1	1	10	10	1	1	1	1	10
Costa	1	10	10	1	1	1	1	1	1	1	10	10	1	1	1	1	10
Fabian	1	10	10	1	1	1	1	1	1	1	10	10	1	1	1	1	10
Hardnett	1	10	10	1	1	1	1	1	1	1	10	10	1	1	1	1	10
Figgs	0	10	10	1	1	1	1	1	1	1	10	10	1	1	1	1	10
Mitchem	1	10	10	1	1	1	1	1	1	1	10	10	1	1	1	1	10
Grace	0	10	10	1	1	1	1	1	1	1	10	10	1	1	1	1	10
Gomez	1	10	10	1	1	1	1	1	1	1	10	10	1	1	1	1	10
Morataya	1	10	10	1	1	1	1	1	1	1	10	10	1	1	1	1	10
Wuiles Santiago	1	10	10	1	1	1	1	1	1	1	10	10	1	1	1	1	10
Gildoontiveros	1	10	10	1	1	1	1	1	1	1	10	10	1	1	1	1	10
Jarvis	0	10	10	1	1	1	1	1	1	1	10	10	1	1	1	1	10
	0	10	10	1	1	1	1	1	1	1	10	10	1	1	1	1	10

The other parts of the model do not require direct user input. Table 7 is an excerpt from the score matrix ($Score_{sr}$ for all values of s and r), showing results from calculations using the availability and specialization matrix described above, and the history matrix which keeps track of each of the different types of surgical cases performed by each technician.

Table 7. Score Matrix

OR Staff		1 Ortho	2 Ortho	3 Add On	5 Plastics	6 Gen Surg	7 Gen Surg	8 Plastics	9 Add On	10 Gen Surg	12 Ortho	13 Ortho	14 Gyn	15 Vasc	16 CT	17 Neuro	18 Ortho
McKew		1.7	1.7	5.2	1.7	1.7	1.7	1.7	5.2	1.7	1.7	1.7	1.7	9.3	9.3	9.3	1.7
Mitchell		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Beben		1.7	1.7	5.2	1.7	1.7	1.7	1.7	5.2	1.7	1.7	1.7	1.7	9.3	9.3	9.3	1.7
Wright		1.7	1.7	4.5	1.7	1.7	1.7	1.7	4.5	1.7	1.7	1.7	1.7	9.3	9.3	8.6	1.7
Fellman		1.7	1.7	4.5	1.7	1.7	1.7	1.7	4.5	1.7	1.7	1.7	1.7	9.3	9.3	8.6	1.7
Capuli		1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	9.2	8.4	7.5	1.8
Allsup		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chavez		1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	9.3	7.8	7.8	1.8
Lumby		1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	8.4	8.4	8.4	1.8
J Sanchez		1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	8.4	8.4	8.4	1.8
Seal		2.4	2.4	1.7	1.7	1.7	1.7	1.7	1.7	1.7	2.4	2.4	1.7	7.9	8.6	8.6	2.4
Cummings		1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	8.4	8.4	8.4	1.8
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
E Sanchez		5.8	5.8	1.7	1.7	1.7	1.7	1.7	1.7	1.7	5.8	5.8	1.7	1.7	1.7	1.7	5.8
Kennedy		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Martin		5.8	5.8	1.7	1.7	1.7	1.7	1.7	1.7	1.7	5.8	5.8	1.7	1.7	1.7	1.7	5.8
Costa		6.3	6.3	1.8	1.8	1.8	1.8	1.8	1.8	1.8	6.3	6.3	1.8	1.8	1.8	1.8	6.3
Fabian		5.8	5.8	1.7	1.7	1.7	1.7	1.7	1.7	1.7	5.8	5.8	1.7	1.7	1.7	1.7	5.8
Hardnett		5.8	5.8	1.7	1.7	1.7	1.7	1.7	1.7	1.7	5.8	5.8	1.7	1.7	1.7	1.7	5.8
Figgs		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mitchem		6.3	6.3	1.8	1.8	1.8	1.8	1.8	1.8	1.8	6.3	6.3	1.8	1.8	1.8	1.8	6.3
Grace		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gomez		5.8	5.8	1.7	1.7	1.7	1.7	1.7	1.7	1.7	5.8	5.8	1.7	1.7	1.7	1.7	5.8
Morataya		6.3	6.3	1.8	1.8	1.8	1.8	1.8	1.8	1.8	6.3	6.3	1.8	1.8	1.8	1.8	6.3
Wuiles Santiago		6.3	6.3	1.8	1.8	1.8	1.8	1.8	1.8	1.8	6.3	6.3	1.8	1.8	1.8	1.8	6.3
Gildoontiveros		6.3	6.3	1.8	1.8	1.8	1.8	1.8	1.8	1.8	6.3	6.3	1.8	1.8	1.8	1.8	6.3
Jarvis		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The history matrix consists of two separate matrices the first of which is the history of cases performed by a technician for a specific type of surgical case. The surgical case types include Orthopedics, General Surgery, Add-On cases, Gynecology, Cardio Thoracic, Neurosurgery, Plastic Surgery, and Vascular Surgery. The second history matrix depicts the resulting history after the Premium Solver add-in is run for the specific day. Both of these matrices are presented in Table 8.

Table 8. History Matrices (H_{sr})

The table shows summary assignment data for a subset of technicians by case type and operating room after one week of daily assignments. CL is short for Clinic in the table.

	1,2,12,13,18 Ortho	6,7,10,CL Gen Surg	3,9 Add On	14 Gyn	16 CT	17 Neuro	5,8,CL Plastics	15 Vasc	Sum
Staff 1	1	1	6	1	1	1	1	1	13
Staff 2	1	3	1	1	1	1	1	1	10
Staff 3	1	3	1	1	2	2	1	2	13
Staff 4	1	2	1	1	2	2	2	1	12
Staff 5	1	2	1	1	2	3	2	1	13
Staff 6	1	3	1	1	2	2	1	1	12
Staff 7	1	2	1	1	1	1	1	1	9
Staff 8	1	1	1	1	2	2	1	1	10
Staff 9	1	1	2	1	2	2	1	1	11
Staff 10	1	1	2	1	2	2	1	2	12
Staff 11	1	1	2	1	2	2	1	2	12
Staff 12	1	1	1	1	1	2	1	2	10

Staff	1,2,12,13,18 Ortho	6,7,10,CL Gen Surg	3,9 Add On	14 Gyn	16 CT	17 Neuro	5,8, CL Plastics	15 Vasc	Sum	Delta
Staff 1	1	1	7	1	1	1	1	1	14	1
Staff 2	1	4	1	1	1	1	1	1	11	1
Staff 3	1	4	1	1	2	2	1	2	14	1
Staff 4	1	2	1	1	2	2	3	1	13	1
Staff 5	1	2	1	1	2	3	3	1	14	1
Staff 6	1	3	1	1	2	3	1	1	13	1
Staff 7	1	2	1	1	1	1	1	1	9	0
Staff 8	1	1	1	1	2	3	1	1	11	1
Staff 9	1	1	2	1	3	2	1	1	12	1
Staff 10	1	1	2	1	3	2	1	2	13	1
Staff 11	1	1	2	1	2	2	1	3	13	1
Staff 12	1	1	1	1	1	2	1	3	11	1

E. WEEKLY SCHEDULE MODEL

In addition to the daily schedule model, NMCSD also generates a six-week duty schedule with a requirement of five technicians for Monday thru Friday and six technicians on Saturday and Sunday. The duty during weekdays supports cases that start during the AM shift and finish in the PM shift. This duty is in addition to the regular workday so technicians are available after their normal working hours.

Replacing the room index with a duty index allows us to use the same daily model formulation presented earlier for the six-week model. An additional constraint is that a

Hospital Corpsman 2nd Class is required to be one of the technicians on duty on Saturday and Sunday. To model this we add a constraint requiring an appropriate subset of the variables to sum to at least one. To calculate the objective function coefficients (Score) the six-week model relies on weightings for each day of the week, three for Monday thru Thursday, and two for Friday thru Sunday. We subtract the history of duties from these daily weightings. The resulting values when taken in aggregate for all technicians encourage an equitable distribution of assignments for the entire week. We present an example of this calculation for a technician below where the history is the number of times the technician has been assigned to the corresponding days.

$\text{Score}_{\text{Mon-Thurs}} = 3 - 0.1*(\text{History of Mon-Thur} + \text{History of Fri} + \text{History of Sat-Sun})$

$\text{Score}_{\text{Fri}} = 2 - 0.2*(\text{History of Mon-Thur} + \text{History of Fri} + \text{History of Sat-Sun})$

$\text{Score}_{\text{Sat-Sun}} = 2 - 0.1*(\text{History of Mon-Thur}) - 0.2*(\text{History of Fri}) - 0.3*(\text{History of Sat-Sun})$

In addition to the constraints mentioned earlier, after the first week is scheduled, there is an additional constraint that prevents the technician from being scheduled on back-to-back days.

1. Six-Week Model Excel Implementation

The six-week model is broken into six worksheets, one for each of the six weeks being assigned. Each sheet consists of four distinct parts. The first part includes each technician's availability for scheduling and a matrix for the first seven days of the six-week period. The scheduler must enter a one if the individual is available and a zero if they are not. Table 9 shows a portion of this set-up.

Table 9. Staff and Availability Matrix For Six-Week Schedule

Note. The first column is rank of the staff (Hospitalman through Hospitalman First Class). The second column shows the staff name, and the last seven columns indicate whether a technician is available (1) or not available (0).

	Staff	Mon	Tues	Wed	Thur	Fri	Sat	Sun
HM3	Staff 1	0	0	0	0	0	0	0
HM3	Staff 2	0	0	0	0	0	0	1
HM3	Staff 3	1	1	1	1	1	1	1
HM3	Staff 4	1	1	1	1	1	1	1
HM2	Staff 5	1	1	1	1	1	1	1
HM3	Staff 6	1	1	1	1	1	1	1
HN	Staff 7	1	1	1	1	1	1	1
HM3	Staff 8	1	1	1	1	1	1	1
HM3	Staff 9	1	1	1	1	1	1	1
HM3	Staff 10	1	1	1	1	1	1	1
HN	Staff 11	1	1	1	1	1	1	1

The next part of the model is the past and present history of assignments for the corresponding technician. The present history is updated after Premium Solver is run for the current week. Both histories are presented in Table 10.

Table 10. History Matrix for Six-Week Model

Note. The first column shows the staff name, the next three columns shows the number of assignments for the weeks prior to the current week. The last three columns show the corresponding history for each staff after assignments for the current week. The values show the history of duties with all technicians first having a single duty. The second table shows the resulting duty history after making assignments for the current week.

	Mon-Thur	Fri	Sat-Sun	Mon-Thur	Fri	Sat-Sun
Staff 1	1	1	1	1	1	1
Staff 2	1	1	1	1	1	2
Staff 3	1	1	1	1	1	2
Staff 4	1	1	1	1	1	2
Staff 5	1	1	1	1	1	2
Staff 6	1	1	1	1	1	2
Staff 7	1	1	1	1	1	2
Staff 8	1	1	1	1	1	2
Staff 9	1	1	1	1	1	2
Staff 10	1	1	1	1	2	1
Staff 11	1	1	1	1	2	1

Next is the calculation of the weighted values for each technician. These values are calculated using standard weightings for each day of the week as described above and weightings of the technician's assignment history. The final part of this model is the

actual assignment matrix that is produced by running Premium Solver. Parts three and four are presented in Table 11.

Table 11. Assignment and Calculation Matrix for Six-Week Model

Note. This table shows a portion of the first week of the six-week model. A one in the last column of the assignment matrix indicates the technician has been selected for the duty section. Because only 42 technicians are required each week for duty assignment, not all technicians are selected each week. The Calculation matrix values provide an indication of which technicians are most favorable to select. The first column is rank of the staff (Hospitalman through Hospitalman First Class). The second column shows the staff name, the next seven columns indicate whether a technician is selected for duty on a particular day of the week. The next seven columns show the corresponding Score calculation based on current and prior duty assignments for each staff member.

		Mon	Tues	Wed	Thur	Fri	Sat	Sun		Mon	Tues	Wed	Thur	Fr	Sat	Sun
HM3	Staff 1	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HM3	Staff 2	0	0	0	0	0	0	1	1	0.00	0.00	0.00	0.00	0.00	0.00	1.40
HM3	Staff 3	0	0	0	0	0	0	1	1	2.70	2.70	2.70	2.70	1.40	1.40	1.40
HM3	Staff 4	0	0	0	0	0	1	0	1	2.70	2.70	2.70	2.70	1.40	1.40	1.40
HM2	Staff 5	0	0	0	0	0	0	1	1	2.70	2.70	2.70	2.70	1.40	1.40	1.40
HM3	Staff 6	0	0	0	0	0	1	0	1	2.70	2.70	2.70	2.70	1.40	1.40	1.40
HN	Staff 7	0	0	0	0	0	1	0	1	2.70	2.70	2.70	2.70	1.40	1.40	1.40
HM3	Staff 8	0	0	0	0	0	1	0	1	2.70	2.70	2.70	2.70	1.40	1.40	1.40
HM3	Staff 9	0	0	0	0	0	1	0	1	2.70	2.70	2.70	2.70	1.40	1.40	1.40
HM3	Staff 10	0	0	0	0	1	0	0	1	2.70	2.70	2.70	2.70	1.40	1.40	1.40
HN	Staff 11	0	0	0	0	1	0	0	1	2.70	2.70	2.70	2.70	1.40	1.40	1.40

After Premium Solver is run for each week, the new technician histories are transferred to the following week and the entire process is repeated.

F. IMPLEMENTATION FEEDBACK

Several additional interviews were conducted with NMCSD personnel to discuss the implementation of both models. As a result of each meeting, changes were made until the delivery of the final models. Changes such as accounting for the scheduling of clinics in addition to Operating Rooms, preventing technicians from being scheduled into specific rooms, and minimizing the amount of data entry required by schedulers are all changes from these follow-on interviews. Both final models were run for several days and weeks with actual and fictitious data to ensure the models worked correctly.

V. CONCLUSIONS AND RECOMMENDATIONS

This research commenced by looking for ways to provide a tool to schedule surgical technicians at Navy hospitals. Through the use of extensive interviews at both military and civilian hospitals, one-on-one sessions with surgical technician schedulers at the Naval Medical Center San Diego (NMCSD), the use of Microsoft Excel with Frontline Systems Premium Solver, historical operating room data, and the classic transportation problem, the models developed met all current requirements at NMCSD. Because scheduling requirements at all hospitals are similar, the model developed for NMCSD can be modified with minimal effort to meet scheduling requirements at the other hospitals.

It is clear what this research provides that did not exist before. At all hospitals where interviews with surgical technicians took place, scheduling was accomplished manually. Completing schedules in this manner was not only time and labor intensive but also depended heavily on key personnel. The introduction of the models developed as a result of this thesis changes both of these critical points. In the case of NMCSD, daily scheduling went from taking hours to taking minutes and the six-week schedule also employed went from taking days to complete to taking tens of minutes. Any personnel with minimal training can use the models. The resulting schedules take into account employee availability and prior scheduling, both critical factors to a fair and equitable schedule.

As is the case with any research topic, there are always ways to improve or to continue investigating the subject. With respect to this thesis the following suggestions for further research are presented:

- Using the information gathered in hospital interviews, modify the existing models for each of the hospitals to meet their current scheduling requirements.
- Currently the employee matrices are manually entered and information from corresponding cells must be copied into any new employee cells added. Using Excel Macros, design a user interface that allows the addition or

deletion of surgical technicians that automatically adjust the size of the matrices required to run the Premium Solver Excel add-in.

- Conduct further interviews at the Naval hospitals and conduct quantitative analysis of how long scheduling takes before and after the implementation of the scheduling models to quantify the timesaving.
- There is no military requirement that mandates the use of multiple surgical technicians per operating room case except for training purposes. Normal employment of a single technician is an area of both personnel and cost savings that warrants further investigation.

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